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ABSTRACT

The International Satellite Geodesy Experiment (ISAGEX) was initiated by the French Centre National d'Etudes Spatiales (CNES) in the Autumn of 1969 through a proposal for an International laser and photographic campaign on satellites equipped with laser reflectors. This proposal was a response to three recommendations:

- COSPAR Group 1, Prague 1969, Decision No. 2 invited observers in all countries which could observe PEOLE (launched in December 1970) with laser or optical systems to participate in making such observations.
- The West European Commission for triangulation (Paris 1969) suggested the use of laser ranging to satellites for the scaling of the European geodetic networks.
- The Seminar on Solid Earth and Ocean Physics conducted at Williamstown, Massachusetts, 1969, recommended that the ongoing program of laser tracking of close earth satellites should be carried out for the purposes of measuring plate tectonic motion, polar wobble and earth rotation.

The ISAGEX Experiment was endorsed by the COSPAR XIIIth General Assembly, Leningrad, 1970, Decision No. 2 as an appropriate response to Decision No. 2 of COSPAR XII.

The objective of the program is to collect a set of homogeneous and well distributed precise laser and camera satellite observations for the purpose of dynamic and geometric geodesy considered as a first step towards the study of the earth as a complex elastic body.

The data gathering portion of the experiment extended from December 15, 1970 to August 31, 1971 and consisted of seven three-week saturation tracking

periods. The seven geodetic satellites tracked were BE-B, BE-C, GEOS-I, GEOS-II, DI-C, DI-D, and PEOLE. This report describes the techniques employed by Geodynamics Branch personnel to generate acquisition data for the two GSFC lasers during this experiment.

The distribution of over 121,000 GSFC laser range observations taken during 621 satellite passes are seen to result from the efficiency of the laser tracking operations and the data acquisition/computational procedures employed by GSFC personnel.

Analyses of the quick-look Astrosoviet NAFA-25 camera data acquired during this experiment indicated that the accuracy of these data was on the order of a few minutes of arc. These data were useful in definitive orbit determination.

Use of the quick-look ISAGEX laser data in a dynamic, multi-arc adjustment of the Guam laser coordinates led to a determination of these values to $\sim$15 m. in a center of mass system.

Preliminary geopotential adjustment analyses using consecutive-pass laser data indicated that systematic laser residuals of $\sim$ 5 m. could be reduced to less than one meter by differential improvement of certain low-degree and order tesseral coefficients.

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1. INTRODUCTION

The data gathering portion of the International Satellite Geodesy Experiment (ISAGEX) covered the time period from December 15, 1970 through August 31, 1971 and consisted of seven, three-week intensive tracking periods, each separated by about fifteen days (Reference 1). During each intensive tracking period, specific satellites were selected to be primary targets for laser acquisition. The time periods and selected satellites are shown in Table 1. The interim fifteen day periods were used to: (1) provide quick-look data for maintenance of orbital prediction accuracies through the next intensive tracking period, (2) provide data for long-term studies, and (3) obtain simultaneous observation data. Alternate satellites were designated for those stations whose geographic positions were such that they could not observe PEOLE, due it's 15° inclination.

Sixteen nations took part in the observation acquisition program (Reference 1); they were:

Australia	Greece
Belgium	Japan
Bulgaria	Netherlands
Czechoslovakia	Sweden
Federal Republic of Germany	Switzerland
Finland	Union of Soviet Socialist Republics
France	United Kingdom
East Germany	United States of America

A number of these nations had the data processing and transmission facilities necessary for providing quick-look observation data required for maintenance of accuracte prediction emphemerides. The stations providing quick-look data, and their organizational affiliations, are shown in Figure 1. In addition to the sixteen participants mentioned above, other nations were host to several important tracking facilities of CNES, SAO, GSFC; they were:

Brazil	Italy
Canada	Malagasy Republic
Chile	New Zealand
Ecuador	Peru
England	Senegal
Ethiopia	Spain
India	Union of South Africa

During the data gathering portion of ISAGEX, the two GSFC lasers were located in Greenbelt, Maryland (GODLAS) and Guam Island (GMISLS). GODLAS participated throughout the entire period; GMISLS terminated operations at the end of June, 1971.

Pointing data for the GSFC lasers were computed by the authors. The NONAME Program (Reference 2) was used for all computations (see Appendix for discussion of program capabilities). Active Minitrack beacons on the BE-C GEOS-II and PEOLE satellites provided good observational coverage for those satellites. In this respect PEOLE Minitrack observations from the CNES station in Kourou were of great value for our orbital computations since most GSFC stations were unable to observe this satellite due to its low inclination. Predictions for the other satellites were based solely upon quick-look optical and laser data.

2. COMPUTATION OF LASER PREDICTIONS

2.1 Data Flow

A large number of camera, Minitrack and laser stations were invited to participate in the quick-look data gathering phase of the ISAGEX. These stations provided quick-look data for the purposes of generating satellite prediction ephemerides for pointing the cooperating precision tracking instruments. The 47 stations from which GSFC received quick-look data during the eight-month experiment appear in Figure 1. In order to assure the most timely utilization of quick-look observational data, it was requested that all quick-look data arrive at GSFC within two days of the observation date.

GSFC personnel established two prediction generation schedules, so that full advantage could be taken of the influx of new quick-look data. One schedule was set up for the BE-C, GEOS-I, and GEOS-II satellites. These satellites had either relatively stable orbits (semi-major axis decay due to drag ranged from two meters/month for GEOS-I to 25 meters/month for BE-C) or strong Minitrack data coverage, or both (i.e., GEOS-II). For these satellites, the prediction ephemerides were updated once each week. A second schedule was established for the PEOLE, DI-C, DI-D, and BE-B satellites. These satellites had larger drag perturbations (semi-major axis decay due to drag ranged from 40 meters/month for BE-B to 750 meters/month for PEOLE) and frequent data shortages. For these satellites, predictions were updated twice each week.

The schedules followed are described in Figure 2. On the days designated in Figure 2, a definitive orbital solution was computed using either seven days (in the case of the weekly updates) or five days (for the bi-weekly updates) of the most recently received quick-look data. The output consisted of an

ephemeris tape which extended two weeks beyond the end date of the definitive orbit computation. The ephemeris tape was then used to generate the actual prediction data for the GODLAS and GMISLS lasers.

This system enabled predictions to be in use as soon as two days after the last quick-look data point in the solution. In order to protect the laser sites from some breakdown in the schedule (e,g., computer malfunctions or biased solutions), the prediction periods overlapped several days to ensure the availability of usable drive tapes at the site. This overlapping is shown explicitly for the case of biweekly updates in Figure 2. The overlapping periods also permitted the performance of a quality control function for prediction accuracy, i.e., if the overlapped predictions differed by more than 100-200 milliseconds (in time), the definitive orbit solution could be re-evaluated and recomputed prior to transmission of predictions to the field.

Operational problems were experienced occasionally. These were mainly due to data shortages or computer malfunctions. When data shortages (which were usually due to adverse weather conditions) precluded the computation of accurate new definitive orbits, whatever new data were received were used for improvement of earlier definitive orbits and these orbits were used for prediction generation. Computer, tape drive, magnetic tape, and computer program malfunctions required that orbit computations be re-executed the following night. The presence of overlapping predictions minimized the adverse effects of these problems.

2.2 Prediction Accuracy Performance

The prediction accuracy performance realized during the ISAGEX experiment was evaluated by consideration of the laser site activity reports. The GSFC laser site personnel generate reports of every orbital pass scheduled, which include, where feasible, prediction timing errors for the successfully acquired passes. A summary of this information for the ISAGEX Experiment is provided in Table 2 (Reference 3).

It is seen that half of all the daily acquisition tabulations showed prediction errors of less than 200 milliseconds. Considering only satellites BE-C, GEOS-I and GEOS-II (for which more quick-look data were available and errors due to the modeling of air drag were small), approximately 90% of the timing errors were less than 500 milliseconds.

2.3 Analyses of Astrosoviet NAFA-25 Quick-Look Optical Observations

The ISAGEX experiment afforded GSFC's first opportunity to use quick-look observations from the Astrosoviet NAFA-25 camera network for operational orbit computation. As shown in Table 3, a total of 263 observation pairs were received during the course of the experiment. The predominant amounts of observational data were received for GEOS-I, GEOS-II and BE-B. The high latitudes of the Astrosoviet sites (no site was further south than 40° N) made tracking of the lower inclination satellites difficult.

Reference 4 presented the results of orbital analyses with the NAFA-25 data received during the preliminary ISAGEX experiment. Analyses of a similar nature were conducted using the data received during the ISAGEX experiment. The results of the latter work are summarized in Table 4. Orbital solutions

were computed for fourteen arcs (five GEOS-1, three GEOS-2, three BE-B, two BE-C, one DI-C) containing a combination of Astrosoviet, SAO, and CNES quick-look camera data. These arcs ranged from three to seven days in length. The overall mean absolute value of the Astrosoviet residuals in this study was approximately four arc minutes.

The orbital solutions were obtained using the NONAME Program on the IBM 360/95 computer. NONAME employs Cowell 10th order numerical integration techniques. In the orbital solutions, the following perturbations were modeled:

- Luni-solar perturbations
- Earth's gravity - SAO 1969 Standard Earth
- Solar radiation pressure
- Air Drag

In each case only the six orbit elements were solved for, except for BE-B, BC-C, and DI-C, where a drag parameter was permitted to adjust.

A trial improvement of the NAFA-25 station coordinates was attempted through a dynamic multiple-arc solution employing laser data (in addition to the Astrosoviet, SAO, and CNES optical data). However, due to the limited number of observations available, no significant reduction in the Astrosoviet residuals resulted. The uncertainty of the adjusted values was on the order of 150 to 200 m (Reference 5).

3. DATA ACQUISITION RESULTS

The laser data acquired by GSFC is summarized in Tables 5 and 6, which respectively show the number of passes observed and the number of observations based on preliminary data acquisition field reports. These numbers

imply that the two GSFC trackers observed 25% of all the laser passes during ISAGEX (other contributors included the five-station SAO laser network and the three-station French laser network).

Tables 5 and 6 must also be evaluated in consideration of (1) the inability of GODLAS to observe PEOLE and (2) the cessation of GMISLS operations in June, 1971. However, it should also be noted that the tables are based upon field reports and it is anticipated that the final reduced data will be about 15 to 20% less than these figures.

4. PRELIMINARY RESULTS FROM ISAGEX DATA ANAYLSES

4.1 Adjustment of Guam Laser Station Coordinates

The location of the Goddard laser station on Guam Island provided the opportunity to use satellite observations to connect the local datum on Guam-Lee #7 (Reference 13) to the geocentric reference system used for the other tracking stations. This connection was necessary before definitive analyses could proceed with the GSFC laser data. Preliminary values for the adjusted coordinates of the Guam laser are provided in Table 7. These values were derived in a simultaneous adjustment of data from five satellites: PEOLE, GEOS-I, GEOS-II, DI-D, and BE-C (Reference 3). Orbital arc lengths ranged from two to six days. The overall RMS of residuals for the 47 passes of range data (29 from GMISLS, 18 from GODLAS) was 5.6 m. This residual level is somewhat higher than the precision of the lasers, which is on the order of 30 to 50 cm. The difference is primarily attributed to errors in the low degree and order gravity coefficients.

4.2 Consecutive Pass Data Analysis

A periodic variation in laser range residuals resulting from orbital solutions based upon three or four consecutive passes of data was first noted in BE-C data obtained during the GSFC Preliminary Polar Motion Experiment (Reference 6). Subsequent studies indicated that the residual pattern could be reduced to near-randomness through adjustment of low degree tesseral coefficients.

Similar residual patterns were noted in the quick-look ISAGEX data for satellites PEOLE and DI-C. As is seen in Figures 3 and 4, tesseral coefficient adjustments have significantly reduced residual magnitudes. The PEOLE residual reduction was obtained by differential correction of C(4, 3) and S(4, 3). Several coefficients of degree two through four were adjusted to effect the DI-C residual reduction. The main point of this exercise was not to obtain improved values for certain tesseral harmonic coefficients but to demonstrate that with precision laser data, uncertainties in the coefficient values could be illustrated. Ultimately, with multiple arcs of laser data from all the ISAGEX satellites significant improvements to the earth's gravitational model appear feasible.

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D. Rose of the Orbital Operations Branch, who was responsible for processing all the quick-look data and making it available for subsequent analyses on the DODS Data Base at the 360/95 computer.

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APPENDIX

NONAME MATHEMATICAL CAPABILITIES

The NONAME Orbit and Geodetic Parameter Estimation Computer Program System has the capability of estimating that set of orbital elements, station positions, measurement biases, and force model parameters such that the orbital tracking data from multiple arcs of multiple satellites best fit the model defined by the entire set of estimated parameters. The program is configured to iterate on the adjustment of orbital elements, measurement biases, station timing errors, the atmospheric drag coefficient, and the solar radiation pressure reflectivity parameter for each arc of data. In the multiple arc mode, the common parameters of station positions and specified geopotential coefficients are adjusted after all individual arcs reach convergence. The entire process is repeated until the common parameters meet some designated convergence criteria.

The theory for the NONAME System falls into the areas of orbit prediction and parameter estimation. For orbit prediction, Cowell's method (Reference 7) is used to integrate numerically the satellite equations of motion in rectangular coordinates. The initial conditions for these differential equations are the epoch position and velocity; the satellite accelerations due to the geopotential, the luni-solar potentials, solar radiation pressure and atmospheric drag can be evaluated.

The equations of motion for the satellite are integrated in the inertial coordinate system defined as the true coordinate system of date at 0.0 hours of the day of epoch. The accelerations due to all forces but the geopotential are evaluated in the true coordinate system of date; the geopotential accelerations

are evaluated in the Earth-fixed system and then transformed to the true coordinate system of date. The Earth-fixed coordinate system differs from the true coordinate system of date as a function of the Earth's rotation and the effects or precession and nutation. The secular effects considered are luni-solar precession, planetary precession, and a secular change in obliquity; the periodic effects are nutation in longitude and in obliquity. The secular effects are related to the mean equator and equinox of date.

To position the Sun and Moon, NONAME uses pre-computed equi-spaced ephemeris data in coordinates obtained from a Jet Propulsion Laboratory ephemeris tape. The tabular interval is 1/2 day for the Moon and 4 days for the Sun. The actual ephemerides are computed using Everett's fifth-order interpolation formula.

The positions of the observers are referred to an Earth-fixed coordinate system defined by the mean pole of 1900.5 and the Greenwich meridian. Polar motion is applied to rotate station positions into the Earth-fixed system of date at each observation time. The position of the instantaneous (or true) pole is computed by linear interpolation in a table of observed values for the true pole relative to the mean pole of 1900-1905; the data in the table originates from the BIH publication "Circular D." Since it is frequently desirable to define station positions in a spherical coordinate system, the station positions are also referred to an oblate spheroid, which is a model for the geometric shape of the Earth as determined by values for the Earth's semi-major axis and the flattening.

The program uses Cowell's method for the direct numerical integration of the equations of motion to obtain values of position and velocity and also to integrate the variational equations to obtain the position partial derivatives. To

integrate the position components of the equations of motion, a Störmer predictor is applied, followed by a Cowell corrector. The velocity components are intergrated using an Adams-Bashforth predictor, followed by an Adams-Moulton corrector. Both are ten point multi-step methods requiring two derivative evaluations on each step. The variational equations are integrated using only corrector formulae.

The integrator output occurs on even integration steps. To obtain values at actual observation times, a Hermite interpolation scheme is employed. Modifications to (1) make the step size negative, (2) invert the time completion test, and (3) invert the entire table of back values exist to provide a backwards integration capability.

A variable step mode exists in which the local integration error computed as the difference between the predicted and corrected values of position, is compared with user specified upper and lower bounds to determine whether the step size should be halved or doubled. In either case, the tables of back values must be modified to be compatible with the new step size. Halving is achieved by a Hermite interpolation for mid-points on the back position, velocity, and acceleration values, while doubling is achieved by discarding every other time point in the table of back values.

Since each step of the integration requires the knowledge of past values of the solution that is not available at the beginning of the process, an integration starting scheme is necessary. The system uses the method proposed by W. Romberg in which the Euler-Cauchy single-step method is combined with Richardson's h^2 extrapolation to generate a sequence of approximate solutions for a fixed time interval h.

The bulk of the force model computations are due to the representation of the Earth's gravity field by the potential of an ellipsoid of revolution, plus small irregular variations. These variations are expressed by a sum of spherical harmonics. Third body disturbing potentials are used to model the forces on the satellite due to solar and lunar gravitational attractions. The calculation associated with solar radiation pressure is performed in consideration of the satellite's presence in the Earth's shadow. For the atmospheric drag problem, the cross sectional area of the satellite and the coefficient of drag are treated as constants. The atmospheric densities are determined from an atmospheric model proposed in 1965 by Jacchia (the Jacchia-Nicolet model) and later Jacchia papers (References 8-12). Solar and geomagnetic activity data, which affect the exospheric temperature, are obtained from the Environmental Science Services Administration in Boulder, Colorado (Department of Commerce).

In the parameter estimation problem, observational data are pre-processed to put the observation and its computed equivalent in a common time and spatial reference system and to make corrections to observations to model certain physical effects. The extent of data pre-processing is as follows:

1. Transformation of all observation times to A1 time at the satellite.
2. Referral of right ascension and declination observations to the true equator and equinox of date.
3. Correction of range measurements for transponder delay and gating effects.
4. Correction of right ascension/declination observations for diurnal aberration.
5. Corrections for atmospheric and parallactic refraction.

Errors in observations may be handled by applying or determining a measurement bias and/or a timing bias. Also, an editing procedure exists to eliminate data whose residuals fall outside a specified error tolerance.

The parameters which can be determined are the epoch position and velocity of the satellite, force model parameters (other than luni-solar potentials) station positions, and measurement biases.

Since the parameters to be estimated are generally overdetermined by the large number of observational data available, a statistical estimation scheme is employed to determine the best solution for the parameters to be estimated. A partitioned Bayesian least squares method, which makes use of meaningful a priori estimates about the data is used by the system. The Newton-Raphson iteration formula is used to solve the normal equations which result from parameter-observation relationships.

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Table 1

ISAGEX Intensive Tracking Periods (1971)

Tracking Period	Primary Targets	Alternate Target
1. January 5-25	PEOLE, GEOS-I, BE-B	D1-D
2. February 15-March 8	PEOLE, GEOS-I, BE-C	D1-D
3. March 25-April 15	PEOLE, GEOS-II, BE-B	D1-C
4. April 29-May 20	PEOLE, GEOS-II, D1-D	GEOS-I
5. June 5-26	PEOLE, GEOS-I, GEOS-II	D1-C
6. July 13-31	PEOLE, GEOS-I, GEOS-II	D1-D
7. August 10-30	PEOLE, GEOS-I, GEOS-II	BE-C

Table 2

ISAGEX Prediction Error (Δt) Distribution by Satellite (in milliseconds)

Satellite	Number of Acquisitions*			
	$0 \leq \Delta t \leq 200$	$201 \leq \Delta t \leq 500$	$501 \leq \Delta t \leq 1000$	$1001 \leq \Delta t$
BE-B	11	8		
BE-C	50	49	19	2
GEOS-1	66	23	5	
GEOS-II	72	9	4	1
DI-C	3	3	3	18
DI-D	11	11	14	12
PEOLE	6	10	9	19
TOTALS	219	113	54	52

*When more than one acquisition was made in a given day, an average prediction error was computed and only one value was tabulated for that day.

Table 3

Astrosoviet Quick-Look Data (NAFA-25) Pairs Received During ISAGEX*

Station	GEOS-I	GEOS-II	BE-B	BE-C	DI-C	DI-D	Total
Vologda	6	19	21				46
Erevan	3		3	5	6	2	19
Kiev	18	12	14				44
Krasnodar	3		4				7
Novosibirsk		3	8				11
Riazan	25	11	5				41
Tartu	4	6	6				16
Tashkent	22	2	3	23	8	21	79
TOTAL	81	53	64	28	14	23	263

*A data pair consists of a right ascension and a declination measurement at some designated time.

Table 4

Summary of Mean Absolute Values of Astrosoviet Residuals

in 14 Orbits During the Period of January 23 - June 2, 1971

Station	Right Ascension*		Declination*		Total Obs.		Obs. Rejected (percent)
	No. of Obs.	Mean Residual	No. of Obs.	Mean Residual	Used	Avail.	
Vologda	28	209	25	129	53	68	22
Erevan	7	418	6	349	13	20	35
Kiev	22	216	22	301	44	80	45
Krasnodar	4	138	3	215	7	14	50
Novosibirsk	5	457	5	181	10	12	17
Riazan	27	176	31	135	58	68	15
Tartu	10	218	9	171	19	20	5
Tashkent	36	329	32	305	68	96	29
TOTAL	139	253	133	218	272	378	28

*Units are topocentric seconds of arc

Table 5

ISAGEX Laser Passes as a Function of Station and Satellite

	PEOLE	GEOS-I	GEOS-II	BE-B	BE-C	DI-C	DI-D	Total
GODLAS		77	62	15	128	31	61	374
GMISLS	69	54	57	8	35	8	16	247
TOTAL	69	131	119	23	163	39	77	621

Table 6

ISAGEX Laser Returns as a Function of Station and Satellite

Satellite Stations	PEOLE	GEOS-I	GEOS-II	BE-B	BE-C	DI-C	DI-D	Total
GODLAS		18442	11556	3275	26535	6796	13308	79912
GMISLS	8237	11521	11495	617	5618	1112	2883	41483
TOTAL	8237	29963	23051	3892	32153	7908	16191	121395

Table 7

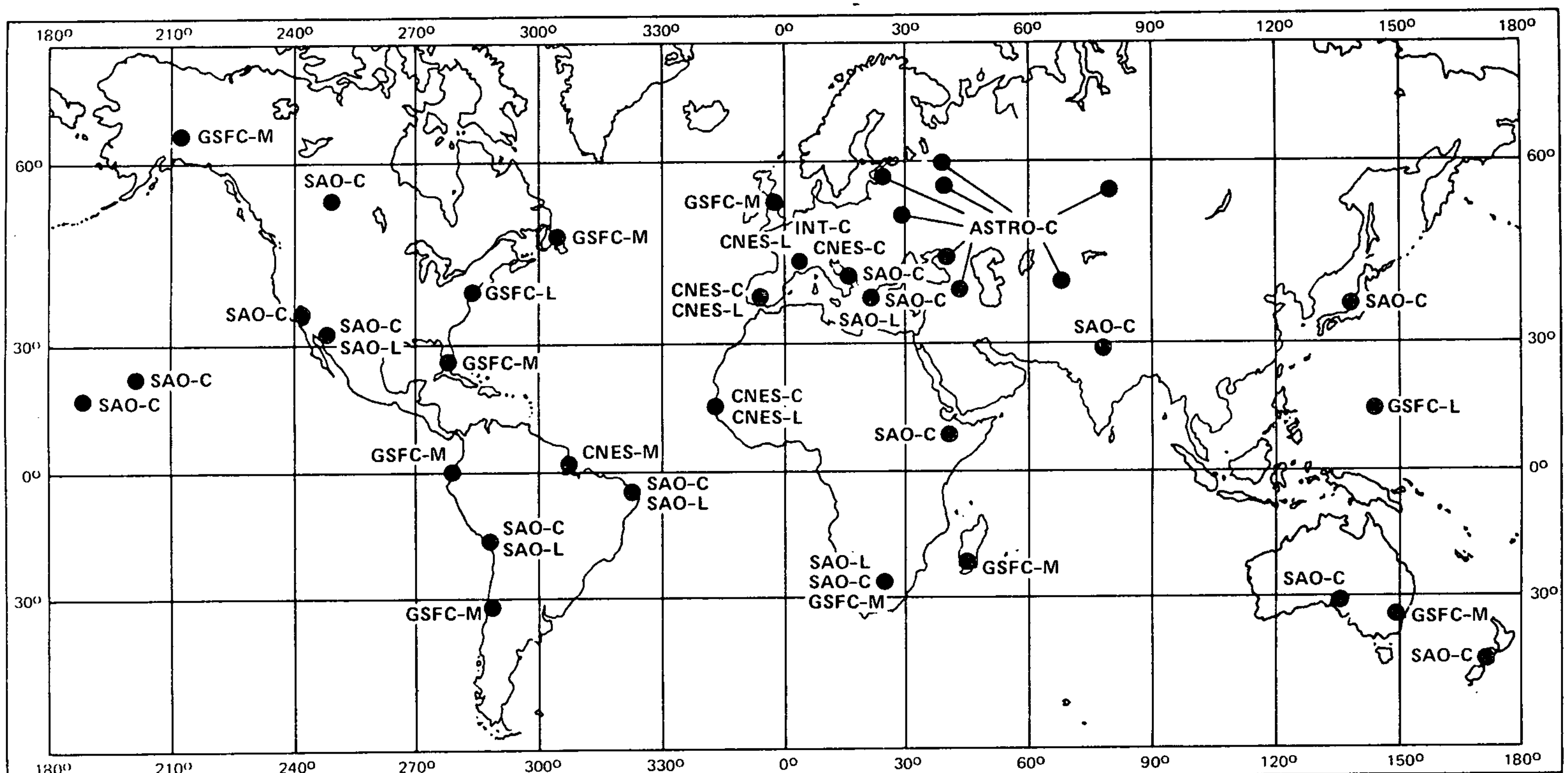
Preliminary Guam Station Estimation

Satellite	Station	No. of Passes
PEOLE	GMISLS	7
GEOS-I	GMISLS GODLAS	9 5
DI-D	GMISLS GODLAS	3 5
GEOS-II	GMISLS GODLAS	2 3
BE-C	GMISLS GODLAS	8 5
TOTAL	GMISLS GODLAS	29 18 — 47

	Geod. Lat.	E. Long.	Ell. Ht.
Initial Coord. (Local Datum) Lee #7*	$13^{\circ}18'28.6136''$	$144^{\circ}44'5.3746''$	85.873m
Final Coord. GSFC Geocentric System†	$13^{\circ}18'33.4''\pm.5''$	$144^{\circ}44'13.3''\pm.5''$	127m±15m

*Referred to an ellipsoid with: semi major axis = 6378206 meters 1/f = 294.98

†Referred to an ellipsoid with: semi major axis = 6378155 meters 1/f = 298.255



GSFC-M - GODDARD MINITRACK
GSFC-L - GODDARD LASER
SAO-C - SAO CAMERA
SAO-L - SAO LASER

CNES-M - FRENCH MINITRACK
CNES-C - FRENCH CAMERA
CNES-L - FRENCH LASER
ASTRO-C - ASTROSOVIET CAMERA (NAFA-25)
INT-C - INTERNATIONAL CAMERA

Figure 1. ISAGEX Stations Contributing Quick-Look Data

Network	Station	Tracking Instrument	Approximate Location Latitude	E. Longitude
GSFC	Fairbanks, Alaska	Minitrack	65°	212°
	Fort Myers, Florida	Minitrack	27°	278°
	Quito, Ecuador	Minitrack	- 1°	281°
	Santiago, Chile	Minitrack	-33°	289°
	St. John's, Newfoundland	Minitrack	48°	307°
	Winkfield, England	Minitrack	51°	359°
	Johannesburg, S. Africa	Minitrack	-26°	28°
	Tananarive, Madagascar	Minitrack	-19°	47°
	Orroral, Australia	Minitrack	-36°	149°
	Greenbelt, Maryland	Laser	39°	283°
	Guam Island	Laser	13°	145°
SAO	Johnston Island	Camera	17°	190°
	Maui, Hawaii	Camera	21°	204°
	Rosamund, California	Camera	35°	242°
	Mt. Hopkins, Arizona	Camera	32°	249°
	Cold Lake, Alberta	Camera	55°	250°
	Arequipa, Peru	Camera	-16°	289°
	Natal, Brazil	Camera	- 6°	325°
	San Vito, Italy	Camera	41°	18°
	Dionysos, Greece	Camera	38°	24°
	Olifantsfontein, S. Africa	Camera	-26°	28°
	Addis Ababa, Ethiopia	Camera	9°	39°
	Naini Tal, India	Camera	29°	79°
	Woomera, Australia	Camera	-31°	137°
SAO	Dodaira, Japan	Camera	36°	139°
	Mt. John, New Zealand	Camera	-44°	170°
	Mt. Hopkins, Arizona	Laser	32°	249°
	Arequipa, Peru	Laser	-16°	289°
	Dionysos, Greece	Laser	38°	24°
	Olifantsfontein, S. Africa	Laser	-26°	28°
	Natal, Brazil	Laser	- 6°	325°
CNES	Kourou, French Guiana	Minitrack	5°	307°
	Dakar, Senegal	Camera	15°	343°
	San Fernando, Spain	Camera	36°	354°
	Nice, France	Camera	44°	7°
	Dakar, Senegal	Laser	15°	343°
	San Fernando, Spain	Laser	36°	354°
	Haute Province, France	Laser	44°	6°
ASTRO	Tartu, USSR	Camera	58°	27°
	Kiev, USSR	Camera	50°	31°
	Krasnodar, USSR	Camera	45°	39°
	Vologda, USSR	Camera	59°	40°
	Riazan, USSR	Camera	55°	40°
	Erevan, USSR	Camera	40°	45°
	Tashkent, USSR	Camera	41°	69°
	Novosibirsk, USSR	Camera	55°	83°
INT	Zimmerwald, Switzerland	Camera	47°	7°

Figure 1. Legend

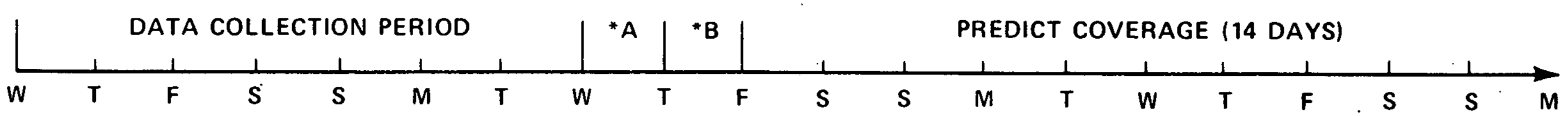
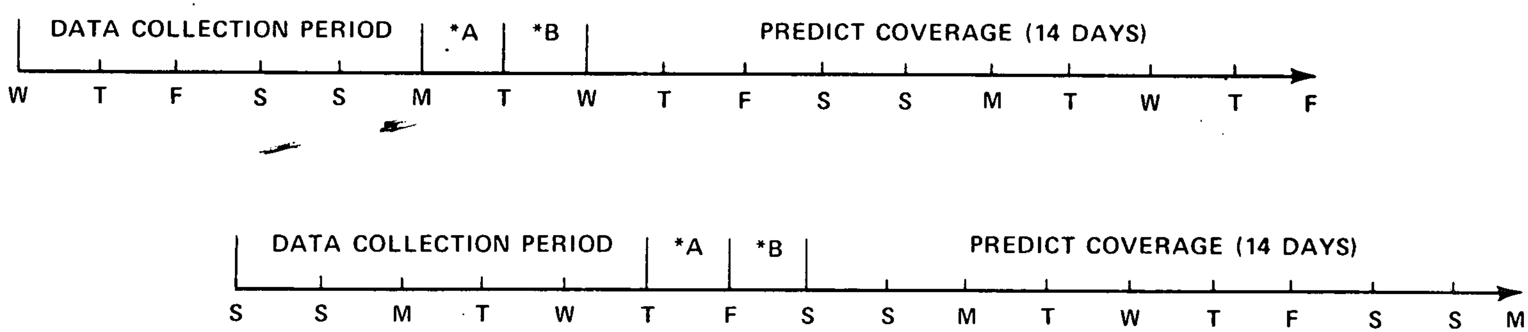


Figure 2.1. Prediction Schedule for BE-C, GEOS-I, GEOS-II



*A - PREDICTION TAPE GENERATED
*B - PREDICTS GENERATED AND DISPATCHED TO FIELD

Figure 2.2. Prediction Schedule for BE-B, DI-C, DI-D, PEOLE

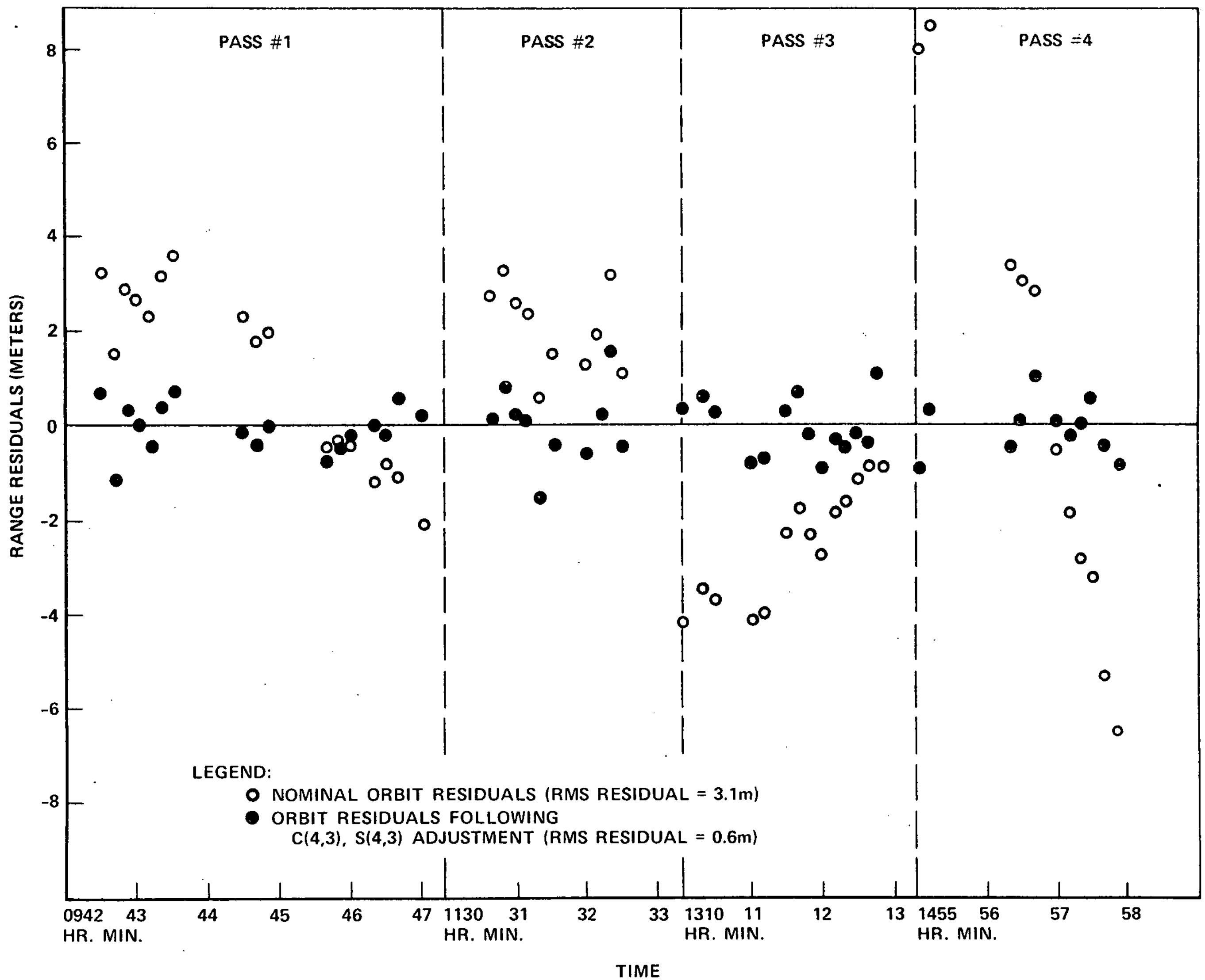


Figure 3. GMISLS Laser Range Residuals - Satellite PEOLE, May 29, 1971

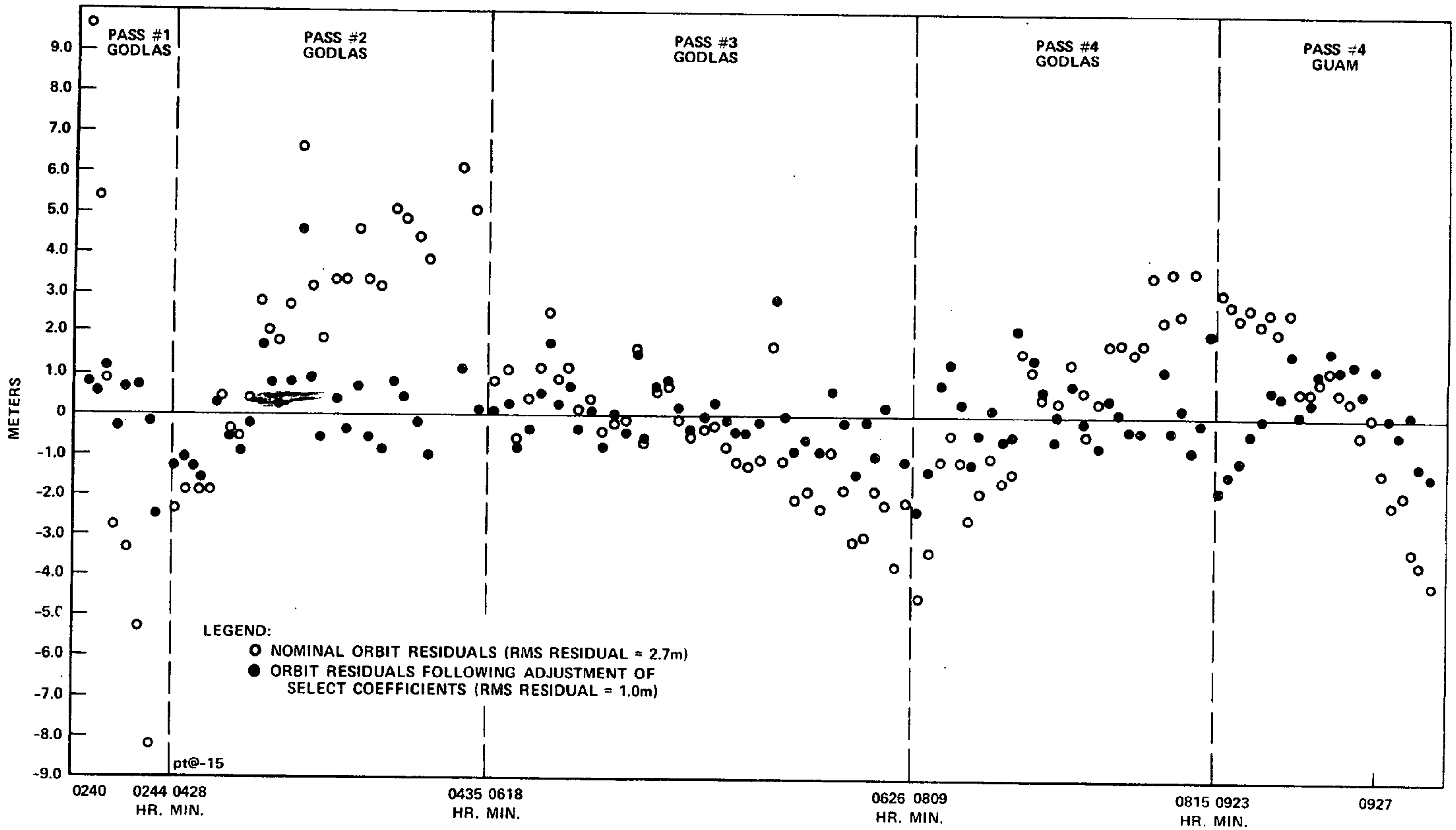


Figure 4. Laser Range Residuals - Satellite DI-C, June 18, 1971